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ACOUSTIC DESIGN OF THE QCSEE PROPULSION SYSTEMS

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SUMMARY

Acoustic design features and techniques employed in the Quiet Clean Short-Haul Experimental Engine (QCSEE) Program are described. The role of jet/flap noise in selecting the engine fan pressure ratio for powered-lift propulsion systems is discussed. The QCSEE acoustic design features include a hybrid inlet (near-sonic throat velocity with acoustic treatment); low fan and core pressure ratios; low fan tip speeds; gear-driven fans; high- and low-frequency "stacked" core noise treatment; multiple-thickness treatment; bulk absorber treatment; and treatment on the stator vanes. The QCSEE designs represent an anticipated acoustic technology improvement of 12 to 16 PNdB relative to the noise levels of the low-noise engines used on current wide-body commercial jet transport aircraft.

INTRODUCTION

The overall objective of the Quiet Clean Short-Haul Experimental Engine (QCSEE) Program is the development of propulsion system technology suitable for future powered-lift, short-haul aircraft. One of the program's major objectives is the development of technology for producing very low propulsion system noise without excessive performance penalties. The program includes the design, fabrication, and static ground testing of two different engines for externally blown-flap (EBF) systems: an under-the-wing (UTW) design, and an over-the-wing (OTW) design. (The designation EBF is sometimes used in reference to a UTW configuration and USB (upper-surface blowing) in reference to an OTW configuration.)

This paper presents a discussion of acoustic design features and techniques employed in the QCSEE program. It emphasizes the unique problems of designing low-noise engines for powered-lift propulsion systems in general. No attempt is made to present a detailed analysis and documentation of the QCSEE engine acoustic designs. Details of the preliminary acoustic design effort are provided in references 1 and 2. Further acoustic design and analysis reports will follow completion of engine testing in 1977.

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## NOISE GOALS

The very stringent noise goals of the QCSEE program present a formidable challenge in aircraft engine design. Not only are the noise goals far more severe than current levels, but a commercial transport employing QCSEE engines must meet these goals without allowance for the additional noise associated with a powered-lift system and with engines sufficiently powerful to allow takeoff and landing on a runway only 610 m (2000 ft) in length. Furthermore, the noise goals are to be achieved without serious penalties in engine performance, size, weight, and cost.

The QCSEE noise goals for both the UTW and OTW powered-lift aircraft with four QCSEE engines producing 400 kN (90 000 lbf) of thrust are illustrated in figure 1. With the engines at takeoff thrust and the aircraft at the altitude at which maximum noise is produced (approx 61 m (200 ft)), the 152.4-m- (500-ft-) sideline noise goal is 95 EPNdB. The same goal applies at approach, with the engines producing 65 percent of takeoff thrust. After the airplane has landed on the runway and the engines are producing reverse thrust equal to 35 percent of takeoff thrust, the noise goal is 100 PNdB.

The acoustic analysis and design effort to achieve these stringent noise goals includes the following elements:

- (1) Identification and assessment of noise sources
- (2) Minimizing source noise
- (3) Application of efficient suppression concepts

The unrestricted pursuit of the last two elements could lead to unacceptable penalties in engine aerodynamic performance, weight, size, cost, and operating economy. In a commercially viable powered-lift propulsion system, each noise source must be reduced only to a near-optimum level relative to an established noise goal in order to produce a "balanced acoustic design."

## ACOUSTIC DESIGN OF BASIC ENGINE

The UTW and OTW engine parameters associated with the acoustic design are listed in table I. As discussed subsequently, a judicious trade-off between acoustic design and engine performance was involved in selecting some of these parameters.

The major noise sources for the QCSEE engines are called out on the sketch of the UTW powered-lift system in figure 2. The single-stage fan generates tones and broadband noise that are radiated out through the inlet in the forward direction and also out through the fan exhaust passage to the rear. The broadband noise from the combustor is radiated rearward. The turbine generates both tones and broadband noise that are propagated through the core exhaust

duct. The only remaining major noise source is a combination of the engine jet noise and the noise associated with the interaction of the jet and the flap surfaces during the production of powered lift, commonly referred to as jet/flap noise.

From prediction equations and correlations and the engine design parameters of table I, noise spectra at takeoff, approach, and reverse thrust as radiated in the forward and aft quadrants from an aircraft in flight must be established for each of the major noise sources. In the example plot of figure 3, the major source spectra for the UTW propulsion system aft noise on takeoff are presented. Plots of this type provide an indication of the amount of suppression required to achieve a balanced acoustic design or, if some suppression requirements are excessive, the need to select another set of design parameters to achieve a better-balanced design.

Figure 3 shows that the jet/flap spectrum is essentially broadband noise that dominates the very low-frequency end of the spectrum. The noise from this source, as shown by the spectrum, falls off rapidly at higher frequencies, of the order of 5 dB per octave. The fan noise radiated rearward includes the blade passing frequency (BPF) tone, which lies in the 1/3-octave band centered at 1000 Hz; the second harmonic of the BPF tone, which lies in the 2000-Hz band; and the fan broadband noise. Dominating the spectral region between the jet/flap noise peak and the fan noise peak is the broadband noise of the combustor, with a peak at about 400 Hz. The combustor noise falls off very rapidly below and above its peak frequency. The broadband noise generated by the low-pressure-fan drive turbine actually peaks at about 8000 Hz on takeoff, but because the high frequencies are reduced by atmospheric attenuation, the propagated turbine noise is represented by the curve with the peak at about 5000 Hz, as shown in figure 3.

Minor noise sources were also considered in the acoustic design. These include compressor noise radiated through the inlet, mechanical noise from the reduction gears, and noise generated by flow over acoustically treated surfaces and airfoils. None of these sources was strong enough to add significantly to the overall engine noise level.

#### Jet/Flap Noise

Although jet/flap interaction noise is generated entirely outside the engine, this noise source is controlled primarily by engine design parameters. Numerous attempts have been made to reduce jet/flap noise by modifying the wing/flap geometry, by employing porous or compliant flap surfaces or edges, and by relocating the engine relative to the flap system. Such efforts, to date, have produced only small reductions in jet/flap noise without lift/drag or thrust-turning efficiency penalties. The flap noise, however, is very sensitive to the velocity of the flow impinging upon the wing/flap system. Hence, the most effective way to reduce the jet/flap noise to any required level, after adopting a preferred configuration, is to reduce the fan and core jet velocities by selecting an engine cycle with suitable fan and core pressure ratios.

Correlations of jet/flap noise experimental results for both model and engine tests showed that the overall sound pressure level (OASPL) from this source varies as  $V^6$ , where  $V$  is the effective engine exhaust velocity at the engine nozzle exit (ref. 3). For unmixed fan and core flows the effective velocity was obtained from a  $v^6$  weighting of the separate velocities. A later correlation and analysis (ref. 4) resulted in a  $V^6$  relation for OTW jet/flap noise and a  $V^{6.7}$  dependency for UTW jet/flap noise.

The sensitivity of jet/flap noise to fan pressure ratio is indicated in figure 4. Effective perceived noise level (EPNL) values for the QCSEE UTW and OTW engine cycles are plotted against fan pressure ratio. The QCSEE UTW jet/flap noise design levels for takeoff and approach were set 3.5 dB below the prediction of reference 3 to allow for advances in UTW flap noise technology corresponding to 1980 engine technology. For a similar reason, the OTW design levels were set 2.5 dB below the reference 3 prediction.

The OTW jet/flap noise curve is approximately 4 EPNdB lower than the UTW curve for a given fan pressure ratio. This is due to the high-frequency portion of the OTW jet/flap noise being shielded to some extent from an observer below and to the side of an aircraft by the presence of the wing. Consequently, for a given jet/flap noise level, the engine can have a higher fan pressure ratio for an OTW system than for a UTW system. This gives the OTW system a possible advantage in size, weight, and performance over the UTW system for a given noise goal.

The levels of figure 4 are based on QCSEE engine cycles and takeoff flap settings. As shown, the QCSEE fan-pressure-ratio design points were set such that the jet/flap noise levels are about 3 EPNdB below the total system noise goal of 95 EPNdB. This arrangement allows the engine and jet/flap noise sources to make approximately equal contributions to the total system noise level and produces a balanced design. Allowing the jet/flap noise to go to levels nearer 95 EPNdB would unduly penalize the engine performance by requiring correspondingly lower engine noise levels. For example, if the jet/flap noise were set at 94.5 EPNdB, a 2.5-EPNdB increase, the engine noise limit would be 85.5 EPNdB, a 6.5-EPNdB decrease. Clearly, if two noise sources are difficult to control or suppress, a balanced design requires that neither be allowed to impose unrealistic levels upon the other.

In accordance with this rationale and engine cycle analyses, the UTW fan pressure ratio was set at 1.27 and the OTW fan pressure ratio was set at 1.34.

#### Fan Noise

The engine design parameters that influence fan noise are labeled in the sketch of the UTW engine system shown in figure 5. Based on correlations of forward-radiated fan noise with fan tip speed, the lowest UTW and OTW fan tip speeds consistent with engine cycle requirements were selected. The selected QCSEE UTW fan tip speed was 290 m/sec (950 ft/sec), and the OTW value was 315 m/sec (1150 ft/sec). These tip speeds are also low enough to prevent

serious inlet noise problems from multiple pure tones caused by interaction of shock waves from the rotor-blade leading edges. The estimated inlet noise levels were substantiated by UTW model fan tests.

A low fan pressure ratio, important in achieving low jet/flap noise, is also important in producing low fan noise. Aft-radiated fan noise for the UTW and OTW engines was estimated by scaling measured acoustic data from full-scale fans and adjusting for pressure ratio, tip speed, and weight flow.

The UTW engine rotor/stator spacing of 1.5 rotor tip chords provides for relatively weak rotor wakes interacting with the stators. An even larger spacing would increase engine length without a proportionate reduction in rotor/stator interaction noise.

The shorter OTW rotor tip chord would require a smaller rotor/stator spacing distance than the UTW spacing distance to provide a spacing of 1.5 rotor tip chords. However, to reduce program costs through commonality of design, tooling, and fabrication, the OTW fan frame was designed with the same spacing distance and basic dimensions as the UTW fan frame. The resultant OTW rotor/stator spacing of 1.93 rotor chords was accepted instead of a smaller spacing for economic considerations.

Another means of minimizing rotor/stator interaction noise is to use a vane/blade ratio (number of stator vanes divided by number of rotor blades) that will cut off the blade-passing-frequency tone, the fundamental tone of the fan. With a vane/blade ratio slightly in excess of 2, the rotor/stator interaction noise does not propagate out the inlet duct, according to the Tyler and Sofrin theory (ref. 5). However, the QCSEE UTW vane/blade ratio was not selected for BPF tone cutoff. It was selected instead to minimize propagation of the second harmonic of the BPF tone ( $2 \times \text{BPF}$ ) according to the theoretical analysis of Mani (ref. 6). In figure 6 the predicted UTW fan exhaust noise spectrum is shown by two curves: one labeled "actual", and the other labeled "noy-weighted." In the actual curve, the BPF tone lies in the  $1/3$ -octave band with a center frequency at 1000 Hz and has a value of about 86 dB, which is about 2.5 dB higher than the second harmonic tone. However, after noy-weighting (adjusting for human annoyance as a function of frequency), the second harmonic tone level is about 5.5 dB greater than the BPF tone. Hence, it was preferable to favor reduction of the second harmonic in the selection of the vane/blade ratio. The concept by Mani was verified in scale-model fan tests with a closely spaced rotor/stator (ref. 7), where the aft-radiated second harmonic tone was 3 to 6 dB lower for near-optimum than for nonoptimum vane/blade combinations. The effect was measured at a rotor/stator spacing of 0.5 but not at 1.5. The effect may have been masked at the larger spacing by rotor inflow turbulence noise, which is believed to be higher in ground tests than in flight situations. Thus, the benefit might be realized in a flight situation, where inflow turbulence is reduced (ref. 8).

The OTW fan, with a vane/blade ratio of 1.18, was also not designed to cut off the fan fundamental tone. Suppression of the fan BPF tone was preferred to the mechanical design and economic compromises necessary to achieve cutoff. The fan noise, both forward and aft, exceeds that of the UTW engine.

The over-the-wing mounting arrangement provides shielding for the fan, combustor, and turbine noise in the aft direction, but not forward. Thus, the OTW engine is forward-noise dominated and requires more inlet and less aft acoustic suppression than the U<sup>T</sup>W engine.

The variable-pitch fan (to permit thrust reversing) and the adjustable exhaust nozzle of the QCSEE UTW propulsion system provide a potential acoustic benefit. By permitting a variety of combinations of blade angle, nozzle area, and fan speed at takeoff and approach thrust requirements, these devices provide considerable flexibility in optimizing acoustic and fan performance trade-offs.

#### Combustor and Turbine Noise

Since both QCSEE engines were designed around an existing General Electric engine core, core noise control was limited to determining combustor and turbine source characteristics and suppression requirements. The core noise was measured and extrapolated to QCSEE conditions. The combustor and turbine spectra are presented in figure 3 for the UTW propulsion system at takeoff as radiated in the aft quadrant.

#### Compressor Noise

Compressor noise estimates indicate this source to be relatively low. In addition, the second- and third-stage tones are above 10 kHz and fall into the low noise-weighted region and also into the high atmospheric attenuation region. The first-stage fundamental tone is at 8 kHz for the takeoff condition. Again acoustic suppression will be relied upon to control any compressor noise that may be present.

#### Reduction Gear Noise

Extrapolations of gear noise data from lower horsepower gear noise tests revealed that gear noise levels would not contribute significantly to the total system noise levels. However, using reduction gears does offer a significant acoustic advantage.

The low fan pressure ratio of the QCSEE engines permitted the selection of a low fan tip speed for low noise. The reduction gear provided high fan drive turbine speeds, reducing turbine size and weight and shifting the turbine noise spectrum to higher frequencies, which are less annoying and more highly attenuated by the atmosphere. This effect is illustrated in figure 6.

## Flow Noise, Splitter Noise, and Strut Noise

From theoretical and experimental studies, working models for predicting flow noise, strut noise, and splitter trailing-edge noise have been formulated. Since these noise sources are a strong function of flow velocity, the aft duct flow path has been designed to limit the average duct Mach number to 0.47 for both QCSEE engines. This is expected to keep these sources well below the suppressed fan exhaust noise.

### ENGINE ACOUSTIC SUPPRESSION

Two different kinds of suppression are employed in the QCSEE program: acoustically treated liners for the flow passages, and the sonic inlet effect. The types of acoustic treatment used in the two QCSEE engines are illustrated in figure 7. The single-degree-of-freedom (SDOF) design employs the conventional honeycomb material bonded between a base plate and a perforated face-sheet adjacent to the flow path. A typical suppression curve for this design is shown in the figure. This treatment is used in the fan inlets, the fan exhaust passages, the fan frame, the stator vanes, the UTW nozzle cowl flaps, and the fan exhaust duct splitter.

The stacked SDOF design is employed in the core noise treatment. Suppression of QCSEE core noise presents a severe problem in acoustic treatment design. The core noise consists of high-frequency broadband noise from the fan-drive turbine and low-frequency broadband noise from the combustor, as shown in figure 3. Because of the short length of the core duct, a "stacked treatment" concept was investigated and adopted for both QCSEE engines. In the compact stacked treatment design, high-frequency treatment consisting of small-hole perforated facesheet over honeycomb is placed along the core exhaust walls. The much thicker low-frequency combustor treatment is placed behind the thin turbine treatment. The rather large resonator cavities are connected to the exhaust passage by a series of tubes passing through the thin treatment. The tubes also extend inward into the resonator cavities, increasing the effective cavity depth. This permits tuning at the very low frequencies (400 or 500 Hz), which normally require much deeper cavities than the 7.5 or 10 cm (3 or 4 in.) available in the core region. The core treatment also has to be designed to withstand high exhaust temperatures of about 810 K (1000° F) and the associated differential thermal expansion during engine startup and shutdown.

The suppression spectrum of the stacked SDOF core treatment is illustrated below the sketch in figure 7. Two peaks, one for low frequency and one for high frequency, are shown, and have been verified by component hot-flow-duct tests.

Bulk absorber treatment is also illustrated in figure 7. This treatment has demonstrated better suppression characteristics than SDOF treatment, based on engine and scale-model tests. The suppression curve is similar to that of the SDOF design, but the peak attenuation is higher and the bandwidth greater

than for a typical SDOF design of equal treatment area. Recent progress by the General Electric Co. in resolving contamination and degradation problems for bulk absorbers has resulted in the development of a Kevlar bulk absorber treatment material that is considered to be flightworthy. Bulk absorber treatment is used in one of the fan inlet designs.

The basic UTW and OTW engine acoustic hardware includes a "boilerplate nacelle" that will accommodate nine interchangeable acoustic panels. In addition to panels for the hard-wall configuration, treated panels for the basic UTW acoustic treatment are to be fabricated. A second treatment will be fabricated if engine acoustic tests indicate a need to adjust the suppression spectrum of the basic treatment. This will be done by designing and fabricating one to six new panels from stockpiled materials to replace corresponding panels in the basic treatment. In a similar manner, an initial-test OTW treatment made up of UTW elements will be modified if needed to satisfy the QCSEE noise goals. The basic construction of these panels is the conventional perforated aluminum facesheet bonded to aluminum honeycomb. An alternate inlet design uses specially treated Kevlar bulk absorber material instead of the honeycomb. A flightworthy composite nacelle that incorporates the best acoustic design and in which the acoustic treatment is integrated into the nacelle load-carrying structure will also be tested on the UTW engine.

In figure 8, curves representing the total system noise (unsuppressed and suppressed) were added to the major noise source spectral plots of figure 3. The curve labeled "total suppressed" becomes relatively flat when no weighted, representing a balanced acoustic design that satisfies the QCSEE UTW takeoff noise goals. A rough indication of suppression requirements is shown by the extent to which each source must be reduced to reach a position well below the total suppressed curve. As shown, considerable suppression of the fan exhaust noise is required in the region of 500 to 10 000 Hz, as much as 20 dB at some frequencies. For the combustor and turbine, on the other hand, suppression is required for less than two octaves, with peak requirements of the order of 5 or 6 dB.

The location and extent of acoustic suppression used in the UTW engine are shown schematically in figure 9. The QCSEE hybrid inlet with a throat Mach number of 0.79 at takeoff was combined with three different thicknesses of acoustic wall treatment to provide 12 to 13 PNdB of suppression. Thus, the hybrid inlet provides very high suppression without the use of inlet acoustic splitters. Based on UTW fan model tests, at takeoff conditions the near-sonic inlet provides about 10 PNdB of suppression and the wall treatment supplies the other 3 PNdB. At approach, the inlet Mach number is less than 0.6, and only the wall treatment is effective. Approach suppression was measured at about 6 PNdB. The wall treatment also provides about 4 PNdB of suppression in the reverse-thrust mode. Hybrid inlet design for powered-lift propulsion systems is discussed in the paper by R. Luidens (ref. 9).

Fan exhaust duct suppression includes multiple-thickness wall treatment on inner and outer walls, a 1.02-m- (40-in.-) long splitter, and treatment in the fan frame, on the pressure side of the stator vanes, and on the nozzle cowl flaps. The fan inlet and fan exhaust treatments have several thicknesses and



are tuned to several different peak frequencies to more nearly match the desired suppression spectrum. The effectiveness of stator vane treatment has not yet been established. The locations of the compressor inlet, turbine, and combustor treatments are also shown in figure 9.

Suppression for the OTW engine is shown in the cross section of figure 10. Comparing figures 9 and 10 reveals the commonality of acoustic and mechanical design for the UTW and OTW engines. With only minor exceptions, the OTW initial-test treatment is the same as that of the UTW engine. The 102-cm (40-in.) splitter was shortened to 76.2 cm (30 in.) by the removal of a specially designed tailpiece. The fan frame treatment is tuned for the OTW BPF tone, and the OTW uses no fan nozzle treatment. The engine acoustic test program was designed to take full advantage of the acoustic hardware commonality of the two QCSEE engines.

Treatment depth, porosity, and tuning frequency for the fan inlet and exhaust acoustic treatments are presented in table II.

Predicted suppression levels for the UTW and OTW propulsion systems on takeoff, approach, and reverse thrust for each noise source are given in table III. At takeoff, which is the most difficult condition with respect to the QCSEE noise goal, the predicted UTW suppression values are 12.3 PNdB for the inlet, 13.4 PNdB for the fan exhaust, 5.1 PNdB for the combustor, and 5.8 PNdB for the turbine. Predicted OTW inlet suppression on takeoff is 12.9 PNdB; the predicted fan exhaust suppression is 12.8 PNdB. Combustor and turbine suppression values are the same as those for the UTW system.

#### PROPULSION SYSTEM NOISE LEVELS

Current estimates of QCSEE propulsion system noise levels are plotted in bar-graph form in figure 11. In the takeoff mode of operation the UTW jet/flap noise level is about 92 EPNdB, which is 3 EPNdB below the noise goal, as originally planned. The engine noise level is about 2 EPNdB below the jet/flap level as well as 2 EPNdB below the allowable engine noise level. The total system noise is about 1.5 EPNdB below the UTW takeoff noise goal, and it may be possible to remove some of the engine acoustic treatment and still satisfy the noise goal. This will be determined after the results of the initial suppressed engine tests are obtained. The predicted UTW approach noise is well below the QCSEE noise goal and thus presents no problem. The suppression required at takeoff provides this margin at approach.

At takeoff the OTW engine and jet/flap noise levels are nearly equal, as designed; and the predicted system level just meets the noise goal. The OTW system approach condition was obtained primarily by reducing the fan speed. The engine noise and the jet/flap noise are both greatly reduced. The system noise is more than 4 EPNdB below the approach limit and presents no particular problem.

Current predictions indicate that neither engine is likely to meet the reverse-thrust noise goal of 100 PNdB. The QCSEE UTW model fan in reverse pitch was noisier than was indicated by earlier tests of model and full-scale reverse-pitch fans. Based on the UTW model tests, the UTW system reverse-thrust noise level will be about 104 PNdB. It is anticipated that by operating the engine at a more optimum blade angle, the reverse-thrust noise level can be lowered. This will be determined during engine tests.

The reverse-thrust noise characteristics of the OTW nozzle are compromised by a variety of other requirements for this nozzle. The D-shaped OTW nozzle must provide flow attachment on the upper wing and flap surfaces; variable exhaust areas for cruise, takeoff, and approach; and acceptable cruise drag and must also serve as a quiet thrust reverser. These conflicting design requirements produce a complex mechanical, aerodynamic, and acoustic design problem. The current OTW design does not represent an optimum acoustic or aerodynamic design. Future development beyond the QCSEE engine tests is required. On the basis of 1/6th-scale thrust reverser model tests, the predicted total system noise level is 104 PNdB.

Although higher than the noise goal, the QCSEE reverse-thrust noise levels are lower than current CTOL engine reverse-thrust levels. Furthermore, since in reverse-thrust operation, the noise source is on the airport runway, the noise footprint does not extend far beyond the airport as it does in the case of takeoff and approach noise footprints. Hence, a severe compromise of other engine requirements to achieve low reverse-thrust noise is probably not desirable.

It is of interest to compare the noise levels of aircraft using QCSEE engines with the noise levels of aircraft that use current high-bypass-ratio, low-noise engines. This task is somewhat complicated by differences in the noise-goal measurement locations, differences in aircraft flight profiles, and the powered-lift aspect of the QCSEE application. So QCSEE was compared with other engines under static ground test conditions, which is a relatively straightforward exercise. The results are shown in table IV. Measured noise levels were adjusted to the same thrust level on a 61-m (200-ft) sideline without jet/flap noise. The current high BPR engines, as represented by the CF6-50 or CF6-6 engines with bypass ratios of 4 and 6, respectively, were used as a reference. Sideline noise levels of aircraft with these engines are about 11 EPNdB better than the FAA FAR 36 requirements (ref. 10). The QCSEE OTW engine, with a bypass ratio of 10, represents a 12-PNdB improvement: 6 PNdB from source noise reduction, and 6 PNdB from suppression improvement. The QCSEE UTW engine, with a bypass ratio of 12, is 16 PNdB quieter than the CF6 engines, with source noise reduced by 10 PNdB and suppression, as for the OTW engine, improved by 6 PNdB over the CF6 engines. Thus the two QCSEE engines represent an engine acoustic technology level as much as 12 to 16 PNdB better than that of the low-noise engines employed on current wide-body jet transport aircraft. However, some of the low-noise techniques used by the QCSEE engines may be inappropriate for some conventional commercial aircraft.

Of course, the design of viable aircraft propulsion systems involves the consideration of many more criteria than acoustics. For example, aircraft

economics is very important. And, although much effort has been put into reducing the performance penalty associated with the low noise levels obtained in the QCSEE propulsion systems, the penalties have not been completely eliminated. Because of the continuing public interest in reducing aircraft noise levels, the extent to which the new technology will be applicable to new aircraft will depend on the direction of future noise regulations, which will be a function of the trade-off between public acceptance and aircraft economics.

### CONCLUSIONS

For powered-lift propulsion systems with stringent noise goals the engine cycle is significantly influenced by the jet/flap noise source such that low fan pressure ratios are required. In addition, engine design parameters must be chosen to generate low noise levels, where possible at frequencies that are easily attenuated and are least annoying to an observer.

The Quiet Clean Short-Haul Experimental Engine (QCSEE) designs employ hybrid inlets in which suppression is provided by a combination of sonic inlet effect and acoustic wall treatment. Core-noise, high-temperature acoustic treatment includes both low- and high-frequency suppression in a unique "stacked treatment" design. Multiple-thickness acoustic suppression is used in fan inlet and exhaust passages. Acoustic treatment is provided in the fan frames, on the stator vanes, and on the under-the-wing (UTW) nozzle cowl flaps. The QCSEE composite nacelle acoustic treatment is integrated into the nacelle load-carrying structure.

Current predictions indicate that the two QCSEE engines will meet the specified noise goals on takeoff and approach. However, in the reverse-thrust mode both engines are estimated to be about 4 PNdB over the goal.

The QCSEE designs are estimated to be as much as 12 to 16 PNdB below the noise levels of the low-noise engines used on current wide-body commercial jet transport aircraft.

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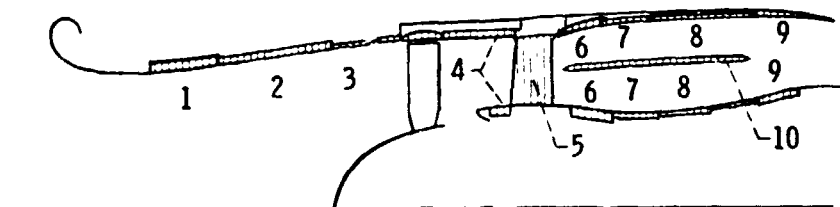
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TABLE I. - QCSEE DESIGN PARAMETERS

[Speed, 41 m/sec (80 knots); altitude, 61 m (200 ft).]

Parameter	Under-the-wing engine	Over-the-wing engine
Fan pressure ratio	1.27	1.34
Fan tip speed, m/sec (ft/sec)	290(950)	350(1150)
Inlet Mach number (throat)	0.79	0.79
Number of fan blades	18	28
Number of stator vanes	33(32 + pylon)	33
Engine weight flow (corrected), kg/sec (lb/sec)	405(894)	405(894)
Blade passing frequency, Hz	920	1760
Vane/blade ratio	1.83	1.18
Rotor/stator spacing, rotor tip chords	1.5	1.93
Bypass ratio	12.1	10.2
Gross thrust (SLS uninstalled), kN (lbf)	81.40(18 300)	93.41(21 000)
Fan exhaust velocity, m/sec (ft/sec)	198(649)	} 231(757)
Core exhaust velocity, m/sec (ft/sec)	238(784)	
Fan exhaust area, m <sup>2</sup> (in <sup>2</sup> )	1.615(2504)	} 1.747(2708)
Core exhaust area, m <sup>2</sup> (in <sup>2</sup> )	0.348(540)	
Fan diameter, cm (in.)	180.4(71)	180.4(71)
Fan rotating speed, rpm	3089	3778

TABLE II. - FAN INLET AND EXHAUST DUCT ACOUSTIC TREATMENT



Section	Cavity depth		Porosity, percent	Forward thrust	Reverse thrust
	cm	in.			
Design frequency, Hz					
1	3.81	1.5	10	1000	1600
2	1.90	.75	↓	1600	2500
3	1.27	.5		2000	3150
4	5.08	2.0		1000	----
5	.76	.3		4000	----
6	5.08	2.0		22	1250
7	2.54	1.0	15.5	2000	----
8	1.90	.75	15.5	2500	----
9	2.54	1.0	15.5	1600	----
10	1.27	.5	11.5	2500	----

TABLE III. - PREDICTED COMPONENT NOISE SUPPRESSION

FOR BOILERPLATE NACELLE

[Sideline distance, 152.4 m (500 ft).]

Acoustic treatment on-	Engine	Takeoff	Approach	Reverse thrust
		Noise suppression, $\Delta$ PNdB		
Fan inlet	Under the wing	12.3	6.3	4.3
	Over the wing	12.9	7.7	7.7
Fan exhaust	Under the wing	13.4	13.4	9.3
	Over the wing	12.8	12.8	12.8
Combustor Turbine	Both	5.1	5.1	5.1
	Both	9.8	9.8	9.8

TABLE IV. - ENGINE NOISE COMPARISON

[61-m-(200-ft-) sideline maximum perceived noise level;  
thrust, 100 kN (22 500 lbf).]

Engine class	Engine designation	Bypass ratio	Source noise reduction, ΔPNdB	Suppression improvement, ΔPNdB	Total noise reduction, ΔPNdB
Current high bypass ratio	CF6-50	4	Ref.	Ref.	Ref.
	CF6-6	6	Ref.	Ref.	Ref.
QCSEE fixed pitch	QCSEE OTW	10	6	6	12
QCSEE variable pitch	QCSEE UTW	12	10	6	16



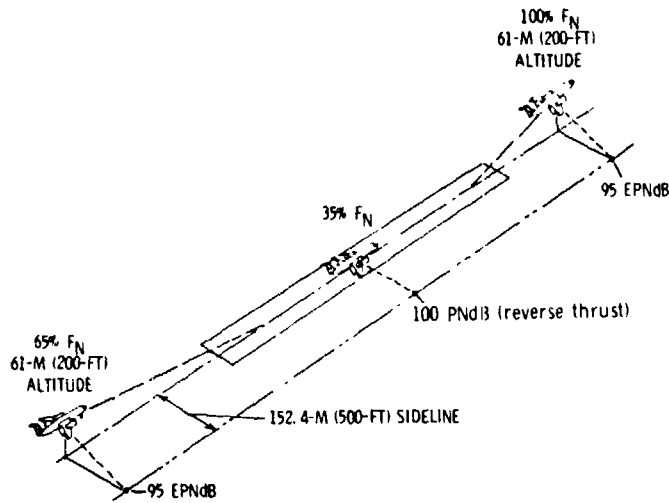


Figure 1.- QCSEE noise goals. Number of engines, 4; takeoff thrust,  $F_N$ , 400 kN (90 000 lb).

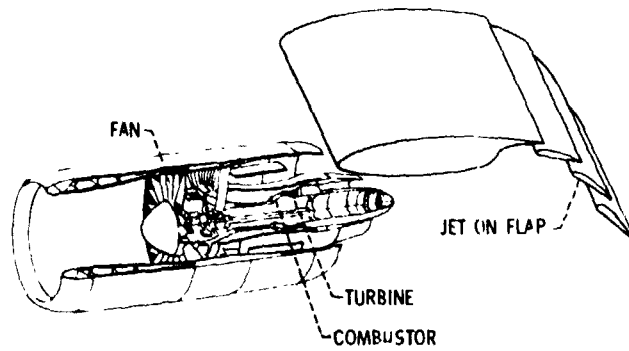


Figure 2.- Major noise sources - under-the-wing engine.

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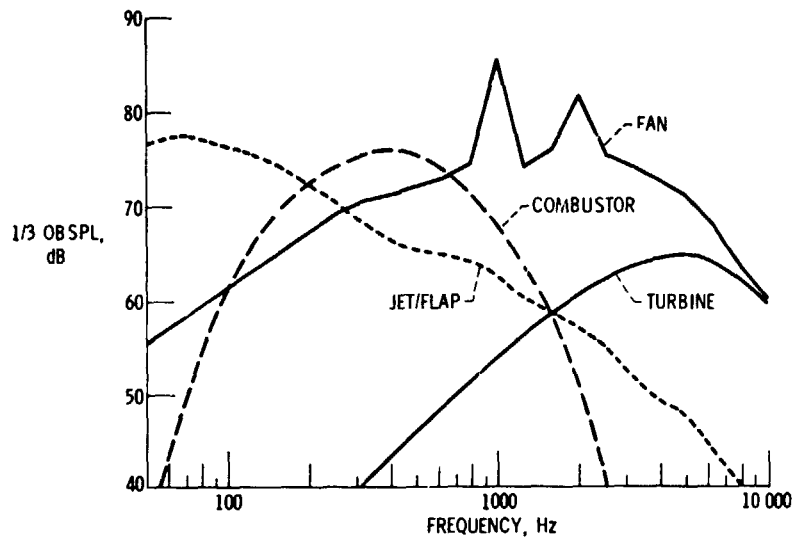


Figure 3.- Takeoff spectra - single under-the-wing engine. Maximum aft acoustic angle, 120°; sideline distance, 152.4 m (500 ft).

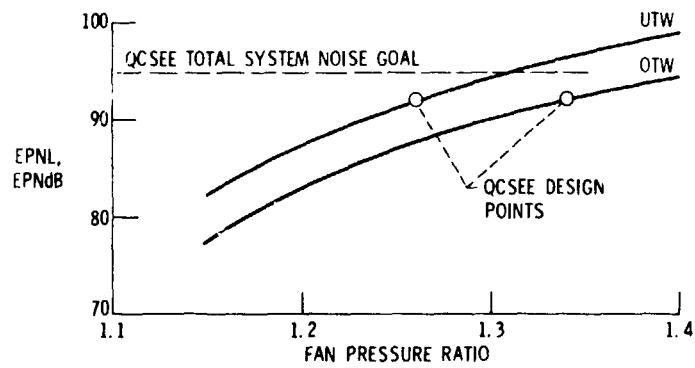


Figure 4.- Effect of jet/flap noise on fan-pressure-ratio selection - four-engine aircraft. Altitude, 61 m (200 ft); sideline distance, 152.4 m (500 ft).

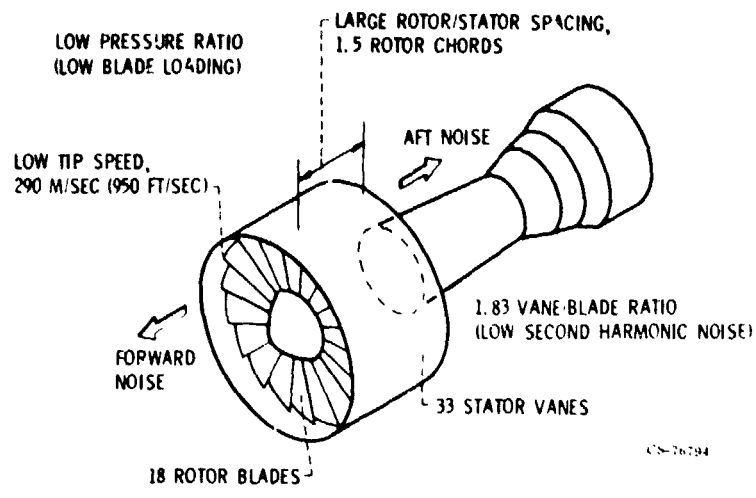


Figure 5.- Low fan source noise - under-the-wing engine.

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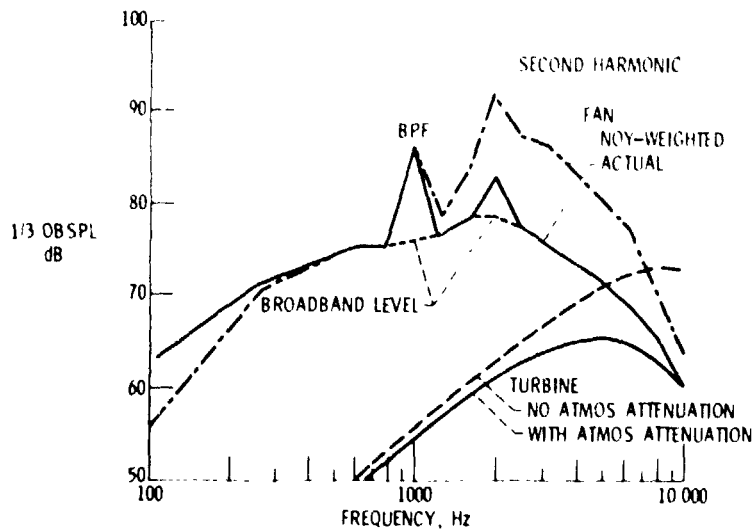


Figure 6.- Frequency effects on perceived sideline noise - under-the-wing fan and turbine exhaust spectra. Sideline distance, 152.4 m (500 ft); altitude, 61 m (200 ft).

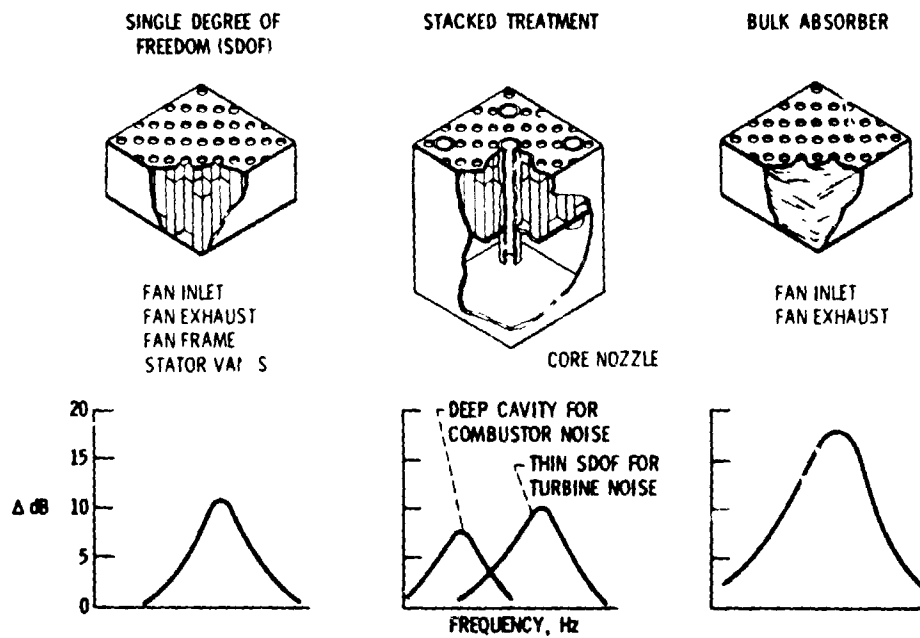


Figure 7.- Types of acoustic treatment for QCSEE engines.

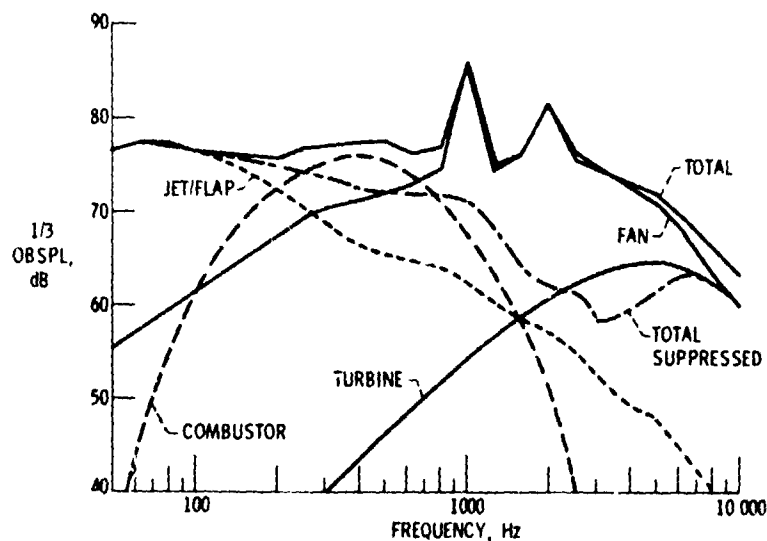


Figure 8.- Takeoff spectra including total and total suppressed noise - single under-the-wing engine. Maximum aft acoustic angle,  $120^\circ$ ; sideline distance, 152.4 m (500 ft).

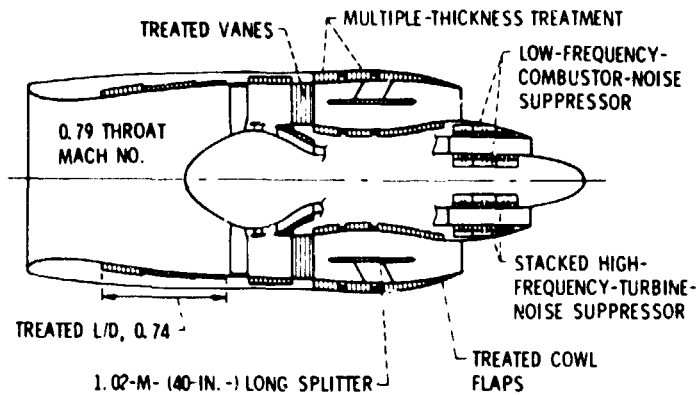


Figure 9.- Acoustic suppression - under-the-wing engine.  
 (Treated L/D is ratio of length of treatment to diameter.)

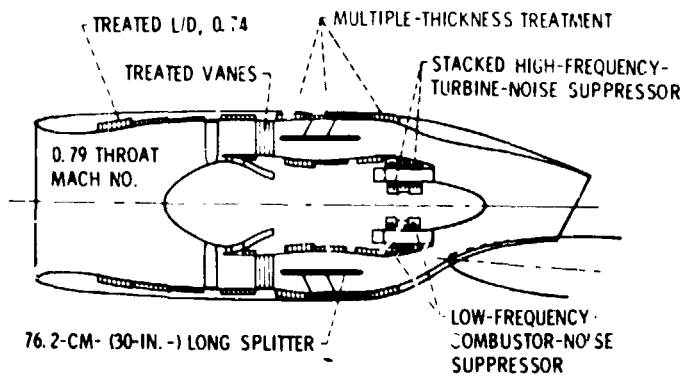


Figure 10.- Acoustic suppression - over-the-wing engine.

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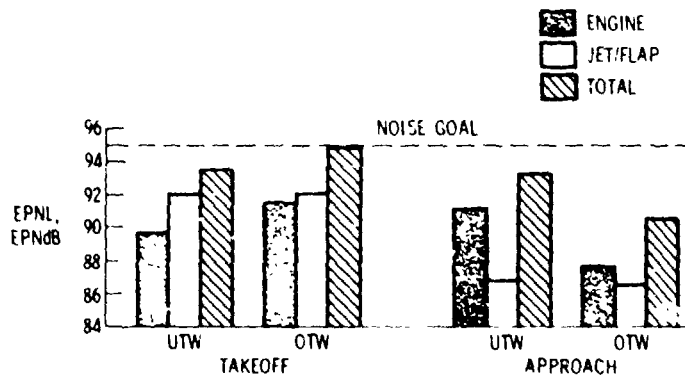


Figure 11.- QCSEE system noise status. Sideline distance, 152.4 m (500 ft).